4
Evaluation and Experimentation

INTRODUCTION

An essential feature of adaptive site management (ASM) is that it allows for a change in remedy—where the chosen approach is falling short of cleanup goals—that takes into account information gleaned on other potentially more effective remedies. One or more factors generally prompt reconsideration of the remedy. As discussed in Chapter 2, the remedy may prove to be ineffective in reaching cleanup goals, which has occurred in thousands of cases. NRC (1994) found that only eight of 77 pump-and-treat systems for groundwater remediation had achieved regulatory standards. In such cases, it makes sense to look for alternatives or at least to adjust or optimize the existing remedy. Even if remediation appears headed toward long-term goals, it may take longer than desired or expected. This can be an acute problem where remediation activities are delaying property reuse, preventing beneficial use of groundwater resources, or depressing property values and discouraging economic activity in the surrounding area. At the former Moffett Naval Air Station, for example, the slow rates of removal of contaminants in groundwater are discouraging NASA, the new property owner, from considering residential construction above the plume.

Sometimes costs escalate as projects encounter unknown obstacles, labor rates rise, or other inputs become more expensive. Or the responsible party's cumulative cleanup expense may outstretch available budgets, forcing cutbacks even at sites where the original financial projections turn out to be accurate. The rising cost per unit mass removal of contamination characteristic of some remedies can inflate overall project costs enormously. When these technologies are unable to meet remedial goals in a reasonable period of time, responsible parties usually seek a change in the hope that a new innovative treatment technology has been developed that is both more economical and effective than the initially chosen technology.

The discovery of new contaminants, higher concentrations of known contaminants, and wider contamination footprints at a site merit a review of the remedy and perhaps the remedial goal. In many cases, the solution may be a simple adjustment of the remedy, like changing the location of extraction wells. In other cases, however, the new discoveries should trigger a rethinking of the entire approach. For example, at Mather Air Force Base, it was discovered after signing a Record of Decision (ROD) covering three oil/water separator sites that petroleum hydrocarbon contamination extended beyond the areas originally identified. An Explanation of Significant Difference—similar to a ROD amendment—was developed proposing to supplement the original excavation remedy with soil vapor extraction and bioventing.

Remedies for soil contamination are more often than not based upon current or reasonably anticipated future land use. When land uses change, such remedies should be reconsidered. This is especially true when a more "intense" land use is proposed that would potentially create additional exposure pathways to human or ecological receptors. Finally, regulatory milestones, whether built into the law—such as the Superfund five-year review—or established through negotiated agreement, call for the periodic review of remedies. At that time, any of the above factors may come to the fore, triggering either an optimization effort or a thorough review of the site remedy. Alternatively, there are situations where a fundamental change in cleanup policy occurs. Potentially responsible parties (PRPs) may seek to conform the remedy at a site to any new cleanup policy, particularly if the remedy has not yet been implemented.

If it is decided that the remedy or remedial goal should be revisited, several courses of action at MDP3 are possible (see Figure 2-7). Deciding on the best course is aided by the parallel track of evaluation and experimentation called for in ASM. The cleanup process at most Navy sites involves a great deal of uncertainty because of an incomplete understanding of contaminant sources, pathways, and receptors, because of the variable performance of technological solutions, and because of the limited ability to establish and maintain proper institutional controls (NRC, 1999a). Obtaining new knowledge on these issues via evaluation and experimentation can reduce the uncertainty inherent in the original remedy selection and improve the cleanup process. For example, if a remedy does not perform as intended, it is often unclear whether the problem is inherent to the remediation approach or is due to inadequate accounting of site conditions in the design of the remediation system. Devoting time and resources to better understanding the site and the remedy can help clarify the situation and suggest ways to either improve the performance of the implemented remedy or provide a rationale for introducing alternative remedies. The quantitative and empirical information generated through evaluation and experimentation is crucial to support any changes of or modifications to existing remedies.

Even in cases where no change to the remedy is anticipated, knowledge gained through activities occurring concurrently with remedy implementation can better define the risks of the remaining contamination—an issue of great importance to stakeholders.

Evaluation and experimentation refer to a broad range of activities that include literature and data interpretation, demonstration studies, and research. Ideally, this should happen on the scale of an individual site, but it can also occur at a much larger, program-level scale. At the level of an individual site, evaluation and experimentation are actions designed to verify the existing hypotheses about the site, to explore the effectiveness of other more risky remediation technologies, or to discover something that can otherwise reduce uncertainty during the cleanup process. Original research may be undertaken to formulate new hypotheses about the site that could then be tested through experimentation ranging in scale from serum bottles to bench-scale columns, pilot-scale columns, and finally field-scale tests with implemented remedies. In addition to interpreting field monitoring data collected as part of routine remedy operation, evaluation and experimentation can also involve synthesis of relevant literature, analysis of operating experiences from other sites, or seeking advice from stakeholders. For these reasons, the success of evaluation and experimentation is linked to the continued development, testing, and demonstration of innovative technologies that has been ongoing at many federal facilities.

Although the main role of evaluation and experimentation at a specific site is to support changes or modifications to remedies to increase overall effectiveness, these activities can also help to lower the costs of remediation, especially at complex sites. Incorporating evaluation and experimentation into the Navy's entire cleanup program could spur development of better technologies to allow cleanup to be accomplished at a lower cost or to a higher state than is presently possible, thereby making sites available for less restrictive uses. This chapter describes the value of evaluation and experimentation to the ASM process, existing research programs that provide information to the Navy on performance and cost of remedial technologies, and suggestions for what the Navy should do to make research part of its cleanup paradigm.

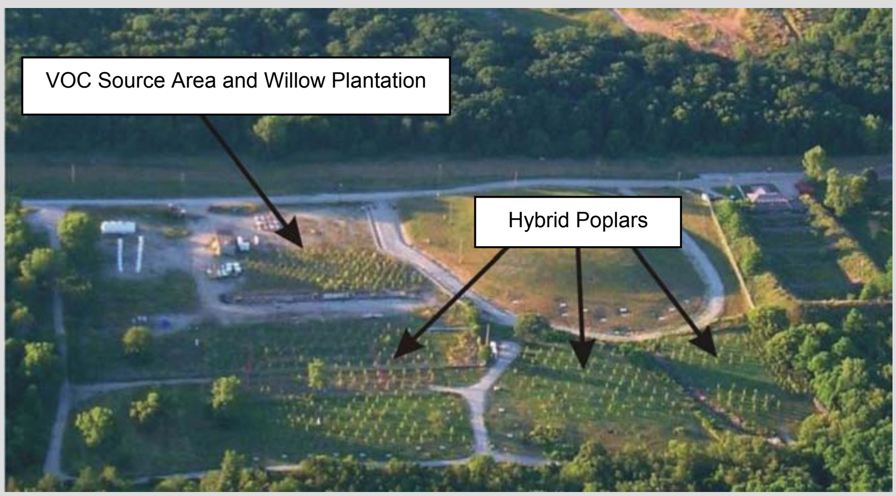
WHY EVALUATION AND EXPERIMENTATION ARE NEEDED

Evaluation and experimentation are necessitated by the ineffectiveness of many selected remedies to meet remedial goals. As documented in Chapter 2 and in previous NRC studies (1994, 1997, 1999a,b), cleanup of contaminated sites is inherently complex because of physical heterogeneity in the subsurface, the presence of nonaqueous phase liquids (NAPLs) and contaminant mixtures (e.g., organics and inorganics), limited accessibility of the contaminants, and difficulties in characterizing the subsurface, among other things. When the performance of a remedy reaches an asymptote before meeting its cleanup objective, it is not solely a function of site complexity and technical limitations, but can also result from insufficient or inaccurate characterization of the site, leading to a flawed design of the remediation system. Assuming that the chosen remedy will not succeed is reasonable for many typical remedies, particularly institutional controls (NRC, 1999a), although the factors contributing to problems at each particular site are likely to be different. The evaluation and experimentation track of ASM specifically accommodates potential problems with remedy effectiveness by improving the understanding of the site (site conceptual model) and suggesting ways to enhance the performance of the existing remedy or to guide the selection of an alternative remedy. The track is a deliberate effort to learn and produce benefits from adversity. Evaluation and experimentation can open up new opportunities to remediate and manage sites more effectively even when problems are not imminent. Examples of where such improved understanding is particularly critical are given in the section below.

If done concurrently with implementation of the remedy, evaluation and experimentation will prevent activities from "stalling" once problems arise and will allow the site managers to make forward progress. Box 4-1 gives a specific example of how a study concurrent with implementation of an initial remedy led to the use of phytoremediation to replace a pump-and-treat system that would otherwise have been operated for the foreseeable future. A more external benefit of the evaluation and experimentation efforts within ASM is that it can create an expanded database on the performance of a remedial technology that will improve user confidence that the technology can provide the desired result under a specific set of conditions. For a responsible party like the Navy that has a large number of hazardous waste sites, the external benefits of investing in learning (i.e., using what is learned in one place at other sites and in future decisions) can be substantial.

BOX 4-1
Evaluation and Experimentation in Site Management at Argonne National Laboratory

The 317 area at Argonne National Laboratory-East has volatile organic compounds (VOCs) in vadose zone soils and underlying groundwater arising from past disposal practices. In 1997 a pump-and-treat system consisting of 13 extraction wells was installed along the site boundary to prevent offsite migration of contaminated groundwater. Although this system was successful in controlling the movement of contaminated groundwater, it provided no benefit from a source remediation perspective, and it likely would have had to operate indefinitely. In 1999, the U.S. Department of Energy, through the Accelerated Site Technology Deployment (ASTD) program, funded the deployment of a phytoremediation system for the 317 area as a potential replacement for the pump-and-treat system. The phytoremediation system consists of approximately 800 hybrid willows and deep-rooted poplars spread over a two-hectare area that included the presumed VOC source zone. The purpose of the phytoremediation system is twofold: (1) to develop hydraulic control over contaminated groundwater movement and so allow the termination of the pump-and-treat system using poplars and (2) to encourage bioremediation of the VOC source area with willows. Numerical flow modeling, which is updated regularly with site-specific data, suggests that by the year 2003, the plantation would successfully control the movement of groundwater, even in the winter when the trees are dormant (Quinn et al., 2001).



Critical Scenarios for Evaluation and Experimentation

Certain remedial approaches involve greater uncertainty than others and necessitate evaluation and experimentation to improve understanding of the mechanisms responsible for performance of the technology and to reduce failure rates. For example, technologies that involve *in situ* reactive treatment, like *in situ* bioremediation, require information on fine-scale subsurface properties, on the presence of indigenous microorganisms and their biodegradation potential, and on the distribution of growth factors (e.g., nutrients, electron acceptors, pH, temperature, and moisture). If supplemental nutrients and electron acceptors must be delivered to the zones of contamination to support bioremediation, then the proper way to manipulate the flow field and achieve mixing must be understood. Intensive monitoring of these parameters during remedy operation is not common and should occur as part of the evaluation and experimentation track if the remedy is to be optimized and reliably used at other sites. The case study in Box 4-2 illustrates how extensive field-scale studies

BOX 4-2
Experimentation and Evaluation in Site Management at Aberdeen Proving Ground

Large plumes of chlorinated VOCs in the shallow subsurface where interactions occur with tidal freshwater wetlands, creeks, and estuaries have presented a challenging environmental problem at Aberdeen Proving Ground (APG), Maryland. Because of the sensitive nature of these wetland ecosystems and the ubiquitous possibility of encountering unexploded ordnance at APG, engineered remediation methods that would require excavation or digging are prohibitively expensive, unsafe, and potentially harmful to these ecosystems. Pump-and-treat was being considered as the primary treatment/containment method for these plumes in the Canal Creek area during an early investigation that characterized the extent of groundwater contamination (Lorah and Clark, 1996). The U.S. Geological Survey (USGS) recognized the potential problems associated with pump-and-treat in this and similar areas and proposed an intensive study of natural attenuation processes in a small wetland area along West Branch Canal Creek where groundwater discharge of chlorinated VOCs was believed to be occurring. It was hypothesized that as aerobic contaminated groundwater discharged into anaerobic wetland sediments, biodegradation of the chlorinated VOCs, in addition to other natural attenuation processes such as sorption and dilution, would attenuate the contaminants before land surface in the wetland or creek channel was reached. An intensive characterization of processes occurring in the wetland porewater and sediment in one area was proposed to provide information that also could be applied to other wetland sites at APG and elsewhere. On this basis, the site manager at APG approved the study, which began in 1992 and resulted in several publications (e.g., Lorah et al., 1997, 1999a,b, 2001).

Reconnaissance-phase installation of drive-point piezometers showed no evidence of VOC contamination in the wetland porewater at some sites but the

Continued

BOX 4-2 Continued

presence of daughter compounds at other sites. It was unclear whether contamination simply was not discharging upward at all locations or if degradation and other attenuation processes had completely removed the VOCs. Closely spaced vertical porewater sampling was necessary in the wetland to adequately characterize the occurrence of biodegradation. For the final monitoring network, additional nested piezometers, screened at discrete intervals in the wetland sediment and to the bottom of the aquifer, were installed along two transects that parallel the general groundwater flow direction in the aquifer. In addition to nested drive-point piezometers, porous membrane diffusion samplers, commonly called "peepers," were used to obtain vertical profiles of redox-sensitive constituents and VOCs in the wetland porewater (Figure 4-1A,B). The peepers made for this study were based on an original design by Hesslein (1976) for investigations of redox processes in lake sediment. The USGS wetland study was the first reported use of peepers for chlorinated VOCs. The profiles from the peepers documented the production and subsequent removal of daughter products from anaerobic biodegradation along upward flowpaths in the wetland porewater (Figure 4-1B). Laboratory microcosms confirmed that vinyl chloride and 1,2-dichloroethylene were the major persistent daughter products from anaerobic degradation of 1,1,2,2-tetrachloroethane, as observed in the peepers. Degradation of trichloroethylene also produced these daughter products. Both the field and laboratory data, however, showed complete degradation of the VOCs under methanogenic conditions. Degradation rates of trichloroethylene and 1,1,2,2-tetrachloroethane measured in the laboratory experiments were extremely rapid, ranging between 0.10 and 0.31 per day (half-lives of about two to seven days) with more rapid degradation occurring under methanogenic conditions. Laboratory experiments also showed the potential for rapid aerobic degradation of 1,2-dichloroethylene and vinyl chloride by methanotrophs in aerobic microzones around plant roots and near land surface.

At the start of this wetland study, limited environmental fate data were available in the literature for one of the major contaminants, 1,1,2,2-tetrachloroethane, and few previous laboratory or field studies had been conducted in wetland environments for any of the chlorinated VOCs. Experimentation, therefore, was especially crucial at this site. Although the results of this investigation have led to recognition by APG site managers and regulatory agencies of the feasibility of monitored natural attenuation as a remediation method for the West Branch wetland plume, a ROD has not yet been obtained, partly because of concerns about the extent of the plumes outside the initial study area. Recent Hoverprobe drilling (see Box 3-6) has allowed further characterization of the plume boundaries to resolve this issue, and APG site management is working toward a ROD that includes monitored natural attenuation as a primary treatment. In addition, early promising results of the West Branch wetland study led to an investigation of natural attenuation of chlorinated solvents in wetlands in the J-Field area of APG, and monitored natural attenuation for the surficial aquifer has been incorporated in a signed ROD for this site. The West Branch wetland study led to collaboration between the USGS and the Air Force Research Laboratory on a project (funded by ESTCP) to demonstrate monitored natural attenuation of chlorinated solvents at other wetland sites and to evaluate methodologies for wetland investigations (Lorah et al., 2002; Dyer et al., 2002). The protocol and results of this ESTCP study should assist other site managers and investigators.

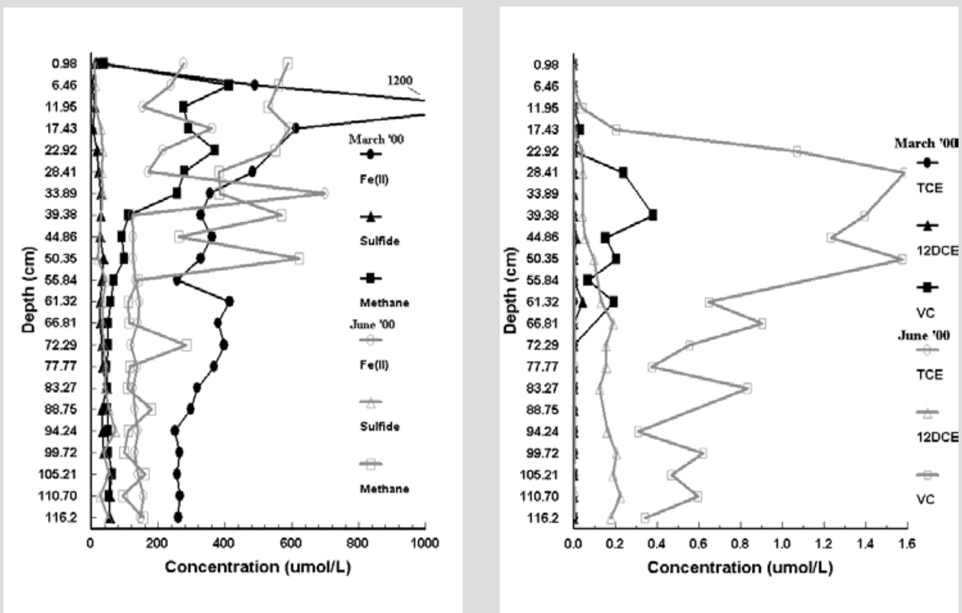


FIGURE 4-1 Concentrations of various organic and inorganic compounds with depth for two time points in 2000. Peeper profiles of (A) redox constituents and (B) VOCs at the West Branch Canal Creek wetland study area. SOURCE: Reprinted, with permission, from Lorah, et al. (2002). © (2002) Battelle Press.

established the biodegradation of chlorinated solvents at an Aberdeen Proving Ground site and led to a shift in the primary site management strategy from pump-and-treat to natural attenuation. It is an example of an approach that embraced experimentation and evaluation and in doing so revealed an opportunity, now being pursued, that may lead to more effective remediation at lower cost than was possible with the original remedy. Furthermore, the protocols for reducing uncertainty in microbial reaction processes developed during the study at Aberdeen Proving Ground should assist other site managers and investigators.

Other examples of remedial approaches with high uncertainty are the use of containment, solidification and stabilization techniques, and institutional controls to reduce the risks at a site through the elimination of one or more exposure pathways. Given the limited experience with enforcing these remedies and their legal complexities, there is a low probability of success over the long term (NRC, 1999a), such that these approaches merit additional evaluation and experimentation. For example, landfills cap designs have evolved from compacted soil to compacted clay to geomembranes and now to alternative designs such as vegetative covers. Because caps have a limited lifetime, monitoring cap performance at select sites is critical to understanding the mechanisms of failure and determining the most effective type of cap for certain environmental conditions. Despite this need, infiltration through caps has been measured at only a few landfills (Khire et al., 1997; Melchior, 1997; Licht et al., 2001). Future decisions on how to repair, replace, and select caps depend on more comprehensive information about landfill cap stability.

For other remedies like dig-and-haul that remove soil contamination, or at sites for which success is more certain (such as those with relatively simple hydrogeology and contaminant chemistry), the need for additional information through the evaluation and experimentation track is not as great.

At some sites, such as contaminated sediments and groundwater systems with extensive fractures (e.g., fractured bedrock or karst) and distributed DNAPL, contaminant inaccessibility and resistance to chemical and biological transformation greatly limit the remediation technologies that can be considered. Under these conditions, risk minimization is the short-term goal because restoration is difficult or impossible with current technologies. Evaluation and experimentation play a role at these sites to understand the current risk and reduce liability and to strive for long-term solutions in addition to optimizing current remedies. Data and information are needed to confirm the exposure pathways and other assumptions used in the risk assessment, to provide greater certainty in the risk calculation, and to determine the degree of remediation needed to reduce risk to acceptable levels. This may, for example, involve site-specific studies of contaminant bioavailability, which is a measure of the potential of a contaminant to be released and reach an ecological or human receptor (for an extensive review of such studies, see NRC, 2003). To ensure greater long-term protectiveness, studies might be undertaken to examine ways to enhance contaminant binding in sediments to prevent leaching and reduce environmental risk. If contaminated sediments are to be displaced by dredging or resuspension, then evaluation and experimentation are needed to identify what fraction, if any, of the contaminants will be released to the water column.

In all of these scenarios, the monitoring data generated during remedy implementation are critical to determining why the technology was unsuccessful and what to change. Evaluation and experimentation do not have to focus exclusively on finding a more effective remedy but can also encompass cost and time issues. Uncertainties about costs add to the reluctance to make modifications to existing remedies or implement alternative remediation systems. Studies could be designed to provide more detailed cost data based on actual site conditions.

The Role of Public Participation

Because evaluation and experimentation are important activities in establishing performance of an implemented remedy and in aiding decisions to change or modify remedies, the public should have input on what studies are conducted at a site. An engaged and informed public is better prepared to participate in the review of technology options and to understand the technical limitations. The affected community may have historical knowledge of the site that can serve as valuable input in planning evaluation and experimentation efforts. Public involvement at this stage can also facilitate studies directed toward the public's concerns, which helps to build trust. Early input from the public on research studies at the site can help to expand the number of acceptable remediation technologies that are considered.

The Role of Expert Panels

There are many situations where an asymptote in cleanup effectiveness has been reached prior to meeting cleanup goals, but there has been no ongoing evaluation and experimentation of the factors contributing to the behavior or of alternative remedial strategies that could improve the situation to help inform decision making. In such cases, expert panels can be used to conduct a short-term analysis of the available options. Although not a substitute for hiring and retaining technically trained staff, the Navy could form multidisciplinary expert panels to provide guidance on the next course of action when the selected remedy is not achieving the desired cleanup goal. Inclusion of experts outside of the Navy in addition to top Navy technical staff would enhance public confidence in the panels as providers of unbiased advice. Panels could include experts from other federal and state agencies, academia, and private consulting firms. Expert panels could be consulted throughout implementation of the remedy and could answer questions concerning the feasibility of achieving technical goals and appropriate modifications to improve performance. Panels could also provide advice on changes that are needed for sites where cleanup is underway and significant difficulties have been encountered. They can help initiate and oversee evaluation and experimentation efforts. For example, the panel might confirm the validity of a proposed site conceptual model, help with knowledge on the contaminant chemistry and behavior, help establish the effectiveness of an alternative remedial technology, and help determine the effectiveness of the monitoring plan. The panel might also be used as a resource for overcoming disagreements between responsible parties, local citizens, and regulators on technical issues. This concept is already being piloted by a joint effort between the Air Force Base Conversion Agency and Interstate Technology Regulatory Council to track remedy performance at six Air Force bases in California (M. Ierardi, Air Force Base Conversion Agency, personal communication, 2002).

MAKING RESEARCH PART OF THE CLEANUP PARADIGM

In order for the evaluation and experimentation track of ASM to be useful, site managers will have to adopt a new, prospective mindset after implementation of the remedy. It will require thinking about what remedies will be available in five years that would allow changing a remedy that is likely to not meet cleanup goals. In cases where the chosen remedy has a better track record, evaluation and experimentation will entail conducting site-specific studies (by remedial project managers or RPMs, contractors, consultants, university researchers, etc.) that occur concurrently with implementation of the remedy and will allow for future optimization of the remedy if cleanup goals are not met. In order to foster research on appropriate response strategies for those contaminants and sites posing the highest risks, the Navy should consolidate its contaminant information, determine relative risk for all of its sites, and establish priorities for site cleanup, ideally with a single database. This will help identify appropriate response strategies for those contaminants and sites posing the highest risks. Improved accessibility of site-specific data, such as in electronic format on the Internet, will help guide research that can most benefit the Navy's remedial program.

The following section describes programs that currently provide some research, development, and field-scale evaluation of remediation technologies and thus may serve an important role in the evaluation and experimentation component of ASM. Participation in these research efforts should lead to improved understanding that will help the environmental restoration program in 30 years as well as right now. The goal of this section is not to design a research agenda for the Navy, as this is generally addressed in other NRC reports (1994, 1997, 1999b, 2000). Rather, the discussion illustrates how each research program can help provide information to ASM and MDP3.

Current Programs

Many programs currently provide research and development, information transfer, and independent review functions that may serve an important role in the evaluation and experimentation track of ASM. Support for innovative technologies covers a broad range of activities. Federal agencies, either acting alone or through federal/private sector partnerships, have taken the lead on research and development of innovative remediation technologies, with over 600 innovative technologies currently under evaluation (EPA, 2000a). In the past decade, the Navy and other military services have supported field demonstration projects using innovative technologies (EPA, 2000a). Several projects at Navy facilities are shown in Table 4-1.

Research and Demonstration

There are two important types of research and development programs—one for basic and applied research to develop new technologies or provide the necessary basic understanding of processes to lead to

TABLE 4-1 Navy Field Demonstration Projects Using Innovative Technologies

Date[a]	Site	Technology	Contaminants
Soil, Sludge, and Sediment			
1993 (report)	NAS Seal Beach, CA	Ex situ bioremediation	BTEX
1999	NAS Yorktown, VA	Ex situ enhanced bioremediation (land farming)	Organic explosives, chlorinated solvents
1994	NAS Yorktown fuel farm	Bioslurping	TPH
1992	NAS Yorktown airfield	Bioventing	Hydrocarbons
open	Small arms firing range, NAS Adak, AK	Phytoremediation and soil washing	Heavy metals
1997	Pearl Harbor, HI	Ex situ extraction from porous surfaces	PCBs, metals
1999	Naval facility, Pearl Harbor, HI	Electrokinetics and electrokinetic heating	Heavy metals
1998 (report)	Hunter's Point Shipyard, San Francisco, CA	Ex situ physical separation/ chemical leaching/soil washing/fluidized bed classifier	Cu, Cr, Pb, Zn
1992	Port Hueneme, CA	Solidification/stabilization	Pb, Cu
Open	NFESC, Port Hueneme, CA	Solvated electron technology	Pesticides
1995	Advanced fuel hydrocarbon national test site, Port Hueneme, CA	Thermally enhanced vapor extraction	TPH
1997	Mare Island Naval Shipyard, Vallejo, CA	Thermal desorption (both thermal blankets and wells)	PCBs
1998	NAS North Island, San Diego, CA	Photolytic destruction	Chlorinated solvents

Groundwater			
1997	Port Hueneme National Test Site, San Diego, CA	Air sparging	Gasoline
open	NAS Fallon, NV	Enhanced bioremediation	Chlorinated solvents
open	NWS, Seal Beach, CA	Enhanced bioremediation	Gasoline, BTEX
1999 (report)	UST Site 23 NAS Point Mugu, CA	Enhanced bioremediation	TCE, VC, cis-1,2-DCE
1995 (report)	NAS North Island, San Diego, CA	Pervaporation	Solvents, degreasers
1993 (report)	Bangor SUBASE	Advanced oxidation process	TNT, RDX
open	Port Hueneme, CA, and other sites	Air sparging	Chlorinated compounds, petroleum
1995	Port Hueneme, CA, Naval Exchange Site	Circulation wells	BTEX
open	NAS Alameda, CA	PRB (Iron and ORC)	cis-DCE, VC, TCE, BTEX
1997	NAS Moffett Field, CA	PRB	TCE, PCE, DCE
1999	Naval facility, Pearl Harbor, HI	Surfactant-enhanced aquifer remediation (SEAR)	Fuel oil
1991	NAS Seal Beach, CA	Vapor extraction	VOCs, volatile fuel

[a]Date (year) of project; usually the start date, but in some cases, the date a report was issued. "Open" means the project is ongoing.
SOURCE: EPA (2000a).

technology development, and one for demonstration and validation of technologies that are past the initial pilot-testing stage. Both types of programs are needed to bring innovative technologies to full-scale application and widespread understanding of their utility. The Navy should support both types of programs to ensure meeting long-term cleanup challenges.

SERDP (http://www.serdp.org)**.** Although there are a relatively large number of opportunities to obtain support for demonstrating and evaluating remedial technologies that have passed the research and development or pilot-testing stage, there are relatively few programs or agencies that support basic research through competitive grants either awarded to external parties or through internal funding. The largest programs are under a corporate Department of Defense (DoD) program, a relatively new Department of Energy (DOE) program, and under the U.S. Environmental Protection Agency (EPA). The DoD's environmental basic research and development program—the Strategic Environmental Research and Development Program (SERDP)—was established in 1990 and is conducted in partnership with DOE and EPA. SERDP operates in concert with DoD's Environmental Security Technology Certification Program (ESTCP, see below), which supports field demonstration and validation of technologies past the basic research and development stage. Total funding for SERDP/ESTCP was about $84 million in FY02. Both government and private sector parties may compete for SERDP funds, and calls for proposals are given annually to address the program's statement of need in the thrust areas of environmental compliance, cleanup, pollution reduction, and conservation. SERDP tends to favor funding of large, multiagency proposals and might only fund one or two new projects annually in each statement of need. The statements of need are selected each year after input from panels of experts (gathered from government, academia, and the private sector) that are convened within the thrust areas. In addition to this core SERDP solicitation that funds multi-year projects, annual solicitations also are released under the SERDP Exploratory Development, or "SEED," program for one-year projects with a maximum funding of $100,000. SEED is designed to provide initial funding for high-risk but potentially high-payoff projects.

ESTCP (http://www.estcp.org)**.** Competitive research grants are provided for field demonstrations of promising innovative technologies through DoD's ESTCP. ESTCP issues two calls for proposals annually—one for DoD agencies and one for other federal agencies and the private sector—for demonstration of cleanup technologies that address their statement of need. The needs change annually and typically address specific *in situ* treatment or containment technologies such as bioremediation or phytoremediation, rapid onsite characterization technologies, and unexploded ordinance detection and remediation. ESTCP's goal is to select lab-proven technologies with broad DoD and market application and provide funding for field demonstrations at DoD facilities. The DoD site or sites used for the demonstration do not need to be selected before a grant is awarded, although it is beneficial to have a potential site identified and a promise of additional support to supplement ESTCP's award. All projects must document the cost and performance of the field trials in reports that have standardized formats.

NETTS (http://www.serdp.org/netts). The SERDP-funded National Environmental Technology Test Sites (NETTS) program also supports demonstration projects by providing three well-characterized DoD sites (Dover Air Force Base, McClellan Air Force Base, and the Navy's Port Hueneme) for applied research and demonstration projects of innovative cleanup, site-characterization, and monitoring technologies. The NETTS program provides site support, such as initial site characterization, demonstration oversight, permitting assistance, and technology assistance, and it also provides infrastructure support, such as access roads, test pads, offices, laboratories, analytical equipment, drill rigs, field vehicles, utilities, and security.

SITE (http://www.epa.gov/ord/site). EPA's Superfund Innovative Technology Evaluation (SITE) program also supports field demonstrations of technologies. There is an annual solicitation for host sites for the demonstration or evaluation of innovative technologies for hazardous waste cleanup in groundwater, soil, or sediment, and an annual solicitation for remedial technologies that can be demonstrated at previously selected sites. Although EPA does not provide funds to the host site, the SITE program assigns an EPA employee to manage each site and covers the cost associated with work plan preparation, field sampling, analysis, and reports. SITE hosts provide infrastructure support to the project and residual waste disposal. Technology vendors provide their own resources for equipment, operation, and maintenance for the demonstration or form a financial agreement with the host site. At the conclusion of a SITE demonstration, a report is prepared that evaluates all available information on the technology, analyzes its applicability to different site and waste characteristics, and presents performance and cost data.

ASTD (http://63.161.144.52/). In 1998 DOE began the Accelerated Site Technology Deployment program (ASTD) to provide additional funding to projects that use innovative technologies with the goal of providing incentives to promote multisite deployment of new technologies. This program differs from SERDP/ESTCP because it is not intended to support demonstrations; rather, it is supporting technologies that have been demonstrated elsewhere and for which evidence of their effectiveness has already been gathered. ASTD is meant to facilitate widespread deployment of these proven technologies. Technologies currently being deployed under the ASTD that are pertinent to Navy sites include permeable reactive barriers, enhanced bioremediation, alternative landfill covers, and thermally enhanced soil vapor extraction. ASTD also differs from SERDP/ESTCP and SITE in that projects are proposed only by RPMs for use specific to a site that they manage. On a smaller scale, the Navy and Air Force accomplish a similar objective of matching innovative technologies to direct use at an RPM's site through Broad Agency Announcements (BAAs) to receive proposals for demonstrations of technologies. Funding is provided for proposals of interest if they can be matched to the needs of an RPM for a site.

STAR (http://es.epa.gov/ncer/grants). EPA competitively funds basic and applied remediation research by external parties through the National Center for Environmental Science to Achieve Results (STAR) grants. Under the STAR grants, researchers are addressing numerous issues relating to remediation, including pesticide remediation, socioeconomic aspects of remediation, bioremediation, phytoremediation, soil and sediment remediation, and remediation of specific classes or constituents such as polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), oxygenates (like MTBE), gasoline, and metals. Through this competitive grant selection process, EPA's Office of Solid Waste and Emergency Response and Office of Research and Development also fund university-based Hazardous Substance Research Centers (HSRCs), which address different theme areas related to environmental research and provide a technology transfer and community outreach function. In addition to EPA, the HSRCs can receive funding from DOE, DoD, academia, and other state and federal government agencies. The five new HSRCs established in 2001 address research on detecting, assessing, and managing hazardous substances in urban environments, on low-cost remediation technologies to remove contaminants from the environment, on developing *in situ* processes for VOC remediation in groundwater and soils, on managing contaminated sediments, and on developing new or improved methods to remediate mine waste sites.

SBRP (http://www-apps.niehs.nih.gov/sbrp/index.cfm). The Superfund Basic Research Program (SBRP) within the National Institute of Environmental Health Sciences also awards grants competitively, although proposals may be submitted only by U.S. universities. The Superfund Amendments and Reauthorization Act (SARA) of 1986 established SBRP to develop methods and technologies for detecting hazardous substances in the environment, to advance techniques for the assessment and evaluation of the effects and risks of hazardous substances on human health, and to assess basic biological, chemical, and physical methods of reducing the amount and toxicity of hazardous substances. In the area of remediation, example projects include biodegradation of PAHs in soil, abiotic dechlorination of chlorinated ethenes, and remediation of gas-phase chlorinated solvents in unsaturated sediments.

ETV (http://www.epa.gov/etv/index.htm)**.** EPA's Environmental Technology Verification (ETV) program was instituted in 1995 to verify the performance of innovative technologies and substantially accelerate their entrance into the domestic and international marketplace (EPA, 2002). The program operates through public/private testing partnerships, and any technology vendor within technology categories selected by stakeholders for verification may participate. Test and quality assurance plans and protocols are developed with the participation of technical experts, stakeholders, and vendors. They are then made available prior to testing, peer reviewed by other experts, and then updated after testing. This program does not fund research, but it can be used by RPMs as a source of reliable information on new technology.

Other programs. The Office of Naval Research (ONR) also provides grants through BAAs for research on characterization of environmental processes and their application to remediation technologies, especially in marine/estuarine sediments. The U.S. Geological Survey provides internal research funds for studying contaminant fate and behavior in hydrologic environments under the Toxic Substances Hydrology Program. This program, which was initiated in 1982, has provided a unique niche in being able to fund long-term process-oriented field research at selected sites. One example is the ongoing project begun in 1983 at a crude-oil spill site in Bemidji, Minnesota, which has provided fundamental knowledge and methods that are widely used to characterize natural attenuation of BTEX at other sites (Cozzarelli et al., 1999). The toxics program is coordinated with EPA, DoD, DOE, U.S. Department of Agriculture, and other Department of Interior (DOI) agencies to select research priorities. Scientists from academia, other federal agencies, and industry commonly are active members of research teams for a site, although much of their funding is provided from sources outside the toxics program. The investigations cover a wide range of contaminants, including chlorinated solvents, BTEX, MTBE, metals, PAHs, and pesticides. A recent addition to the toxics program is a TCE-contaminated fractured rock site in New Jersey, providing the Navy with an opportunity to conduct long-term studies at one of its sites.

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For ASM to be successfully implemented, data and information from the above research and demonstration programs, particularly results that are relevant to the contaminants and problems at their facilities, must be made available to RPMs. This information provides options in case an existing remedy approaches an asymptote prior to reaching cleanup goals. Although support of research and demonstrations at non-Navy sites also is critical in building a database on performance and cost effectiveness for innovative technologies, the Navy should consider emulating DOE's ASTD program. This might be done by expanding the Navy's BAA program to facilitate a direct linkage between the RPMs' need for experimentation at a particular site and available technologies and expert assistance. The model of the national test centers (such as at Port Hueneme), which have hosted technology demonstrations at Navy facilities, should be expanded to include additional facilities.

In addition, because implementing innovative technologies is different from performing the fundamental research necessary to develop innovative technologies in the first place, these test centers should also be considered as candidates for conducting basic research. The above review of the existing major research and demonstration programs shows that there are fewer programs supporting initial basic research and technology development than there are programs for supporting demonstrations or deployment of technologies that are already proven to some extent. Because no single remediation technology has been found that can take care of all or even most of the Navy's complex problems (see Chapter 5), basic research into entirely new technologies will be necessary in order to eventually attain long-term cleanup goals.

Information Transfer

Since 1990, EPA's Technology Innovation Office (TIO) has sought to increase the applications of innovative technologies to the characterization and treatment of contaminated waste sites, soils, and groundwater by acting as a leader in technology transfer. TIO gathers and assesses research ventures of other offices within EPA, of other federal agencies, and of the private sector. TIO spreads information on technologies both through traditional paper publications and extensive web-based information networks. Within the next few years, EPA, the U.S. Army Corps of Engineers, and their contractors expect to gather and evaluate baseline data on all Superfund pump-and-treat systems and optimize the operation of up to 16 systems.

The Federal Remediation Technologies Roundtable (FRTR), which is a partnership formed to exchange information on the development and demonstration of innovative technologies, includes the Army, the Navy, the Air Force, the Corps of Engineers, DOE, DOI, and EPA as members. A focus of the FRTR has been to provide a more comprehensive record of remedial cost and performance at demonstration or test sites. The FRTR also has published review and guidance documents.

A consortium called the Interstate Regulatory Technology Council (ITRC) includes members from over 35 state environmental regulatory agencies that work with federal agencies and other stakeholders to transfer technology information and to help build consistent regulation of new site restoration technologies and other environmental resource problems. The ITRC has technical teams that develop guidance documents on innovative technologies and provides classroom and Internet training on these technologies. For example, ITRC technical teams have produced guidance documents on *in situ* bioremediation, *in situ* chemical oxidation, and permeable reactive barriers. In addition, ITRC has a State Engagement Program that works to obtain multistate concurrence on the guidance documents that are produced, expediting the regulatory acceptance of new and emerging technologies.

In 1992, TIO and the EPA's Office of Research and Development established the Remediation Technologies Development Forum (RTDF), a consortium of industry, government, and academia, to stimulate collaboration between the federal government and private sector in developing innovative solutions to mutual hazardous waste problems. The partners voluntarily share knowledge, experience, equipment, and facilities while jointly participating in research and demonstration efforts with a goal of developing more effective, less costly hazardous waste characterization and treatment technologies. For example, the Bioremediation Consortium of RTDF has conducted several studies at chlorinated solvent-contaminated sites at Dover AFB, Delaware, including a cometabolic bioventing study, a natural attenuation study, and pilot tests of accelerated anaerobic biodegradation that initially used injection of substrates and nutrients and later used bioaugmentation (Grosso et al., 1999; Ellis et al., 2000). Other current RTDF teams focus on phytoremediation, permeable reactive barriers, and diffusion samplers. RTDF teams have provided training courses and manuals on technology procedures.

The individual DoD agencies also have their own divisions that provide an information transfer role to RPMs. The Air Force has supported evaluation of remediation technologies through the Air Force Center for Environmental Excellence (AFCEE) and through the Air Force Research Laboratory (USAFRL), although the USAFRL is in the process of closing down its environmental work. An example of AFCEE involvement in information transfer and implementation of innovative technologies is the development of protocols, which were later reviewed and published as EPA documents, for evaluating monitored natural attenuation at petroleum hydrocarbon and chlorinated solvent sites. AFCEE also completed an evaluation of the performance and cost of implementing natural attenuation as a remedy for fuel and chlorinated solvent contamination at multiple Air Force sites. For the Navy, the Naval Facilities Engineering Service Center (NFESC) provides training and other information transfer activities for RPMs through a variety of programs and initiatives. For example, web-based multimedia tools have been developed that are easily accessible to RPMs, that are updated and revised quickly, that provide a link to technical experts, and that track feedback from users. Furthermore, NFESC organizes the Remediation Innovative Technology Seminar, which provides training to RPMs, regulators, and Navy contractors on new and innovative technologies.

Adopting ASM will require that the Navy continue to participate in RTDF consortia and FRTR activities to remain abreast of available technologies and their applicability to different sites and media. Participation in development and dissemination of interagency guidance documents on promising technologies also would assist in providing reliable information to RPMs and increasing understanding and acceptance of innovative technologies.

Independent Review Panels

The benefits of independent review panels for facilitating decision making during ASM have been discussed previously. In 2000, EPA established an independent review program, called the Optimization of Fund-lead Ground Water Pump and Treat Systems, with the goal of assisting EPA Regions in optimizing existing pump-and-treat groundwater remedies that have been constructed and are being operated by EPA or the states with Superfund money (EPA, 2000b). Individual DoD agencies have all supported independent review panels to examine their environmental cleanup. For example, the Army established the Groundwater Extraction and Treatment Effectiveness Review program to form teams to go into the field to assess existing treatment systems at Army sites and redesign these systems to run more proficiently at lower operational costs. For the Navy, NFESC has successfully deployed "Tiger Teams" to review, evaluate, and optimize environmental restoration efforts at numerous Navy installations. Tiger Teams are panels of internal and external technical specialists that can provide guidance on the most effective strategies to achieve site closure, potentially providing solutions that may not have been conceptualized by installation staff or its contractors.

Obstacles to Research

There are significant obstacles to conducting research in the current environmental restoration program that may inhibit adoption of ASM. These obstacles, and suggestions for how to create incentives to overcome them, can be broadly grouped into the following areas: resource obstacles, regulatory obstacles, timing issues, and socioeconomic barriers.

Resource Issues

Perhaps the most important issue is how to fund evaluation and experimentation activities at an individual site that will require additional resources beyond those needed to implement the chosen remedy. Past experience indicates that military and government officials may be reluctant to provide such additional funds. Historically, there has been a clear line drawn between enforcement and cleanup expenditures and research expenditures, within both EPA and the military. Different EPA offices handle cleanup and research and, as a practical matter, research budgets are separate from cleanup and enforcement budgets within many agencies. For example, although some of EPA's research budget does come from Superfund, the agency research budget is primarily derived from general funds and is allocated annually based on broad research goals, not individual site-specific considerations. Similar trends are apparent in the military, such that it is difficult to get funding under the environmental restoration program for anything labeled as "research." At times, even the use of cleanup funds to supplement a study primarily funded through a program such as ESTCP has been stated to be inappropriate use of these funds. Thus, activities such as conducting treatability tests to later optimize a remedial action at a specific site may be allowed and funded, but it is much more difficult to fund research on a new remedy that is not part of the ongoing site-specific activity. In general, DoD discourages the linkage of actual installation restoration activities with research and development, particularly if the results are primarily useful at sites other than the site where the research is being conducted. Where restoration and research funds are legally different, these distinctions must be observed. This strongly suggests that the Navy (and all federal departments more generally) and EPA should assess the statutory, regulatory, and institutional barriers that prevent cleanup funds from being utilized for research and that prevent research projects from being located at restoration sites.

In addition to these direct funding issues, there is a human resource issue. It is natural to expect resistance to a process that expects cleanup staff to distill new information germane to an already complicated set of operational tasks. Furthermore, hosting a demonstration study at a site inevitably requires assistance from the RPM and others knowledgeable on site specifics in infrastructure, permitting, and regulatory acceptance issues. RPMs often have too large of a workload and little incentive to provide this type of support for a demonstration that may not provide a remedial solution for their sites. In fact, there can be a perception that allowing this demonstration may uncover additional problems at the site, resulting in additional work for the RPM.

Despite these drawbacks, experience at some facilities illustrates the value of combining research and development activities with cleanup. For example, the Navy initially installed the permeable reactive barrier (PRB) at Moffett Field, California, as a pilot-scale installation restoration activity. ESTCP subsequently sponsored the NFESC to validate the performance and cost effectiveness of the PRB technology at Moffett Field for eventual application at other DoD sites, and later SERDP added funds as well. Much of the detailed knowledge of the performance of PRBs is derived from this innovative partnership (NFESC, 1998; Gavaskar et al., 2001). Now that grant funding has expired, it is hoped that the Navy is committed to continuing such low-level expenditures. Thus, there are creative funding mechanisms to enable the incorporation of evaluation and experimentation into site management under the current system, although such results suggest the need to revise policy and even statutes to encourage further linkages.

Box 4-3 discusses a new DOE program—the Accelerated Site Technology Development (ASTD) program —that serves as a useful model for how to pay for evaluation and experimentation activities that focus on the development of innovative technologies. In this case, DOE will pay for a portion of cleanup at certain experimental sites where an innovative but proven technology is proposed for use. The program targets those innovative technologies for which considerable evidence of effectiveness has already been gathered but for which widespread deployment has not yet occurred.

Timing Issues

There are potential timing issues that will arise regarding the evaluation and experimentation track of ASM. For example, will it be possible to obtain research results from site-specific studies during the timeframe of remediation? If not, then the practicality of that research for informing decision making is limited. Second, site managers may perceive evaluation and experimentation as somehow delaying completion of the project because time and resources must be spent on multiple activities. However, this assumes that the evaluation and experimentation activities will not prove useful in optimizing the existing remedy or helping to better understand a technology that will replace the existing remedy. As discussed above, for cases where the technology has limited potential to succeed (as with institutional controls or at sites with DNAPLs and heterogeneous hydrogeology), concurrent study can prevent the cleanup from stalling by providing alternatives when contaminant concentrations level off above the remedial goal.

Regulatory Issues

Regulatory barriers to implementing ASM are discussed in detail in

BOX 4-3
DOE's Accelerated Site Technology Deployment Program

Several DoD programs already discussed including SERDP, ESTCP, and NETTS encourage the development and demonstration of innovative technologies for hazardous waste site remediation. Although these three programs foster technological innovation from basic research and development through demonstration and validation for the DoD complex, the final hurdle for innovative technologies is widespread deployment. Within DOE, the final deployment hurdle is addressed by the Accelerated Site Technology Deployment (ASTD) program. The ASTD program recognizes that obstacles such as regulatory and stakeholder approval, site acceptance, perceived business and technology risks, and simple inertia can prevent the application of new technologies that have the potential for saving money and/or reducing cleanup schedules. The purpose of the ASTD program is to facilitate the use of proven, innovative technologies across the DOE complex.

The ASTD program provides site managers with supplementary funding for projects if innovative but proven technologies are used. For a project to qualify for ASTD funding, the following requirements must be met:

- The site manager proposes an innovative but proven technology that has demonstrated an improvement over the existing site baseline plans.
- The site manager has made a budgetary commitment to use the innovative technology that covers at least 50 percent of the deployment costs.
- A cost/benefit analysis demonstrates the potential for significant life-cycle cost savings over baseline approaches if the innovative technology is used.
- The site manager has identified other sites willing to deploy the technology if initial deployments are successful.
- The site can provide evidence that the necessary regulatory permits will be obtained.

For individual sites, the attraction of a funded ASTD activity is the ability to obtain additional funding above and beyond baseline dollars for completing site environmental restoration obligations.

Sixty ASTD projects were initiated between FY98 and FY00 at 22 DOE sites at a cost of $255.8 million. Over one third of the funding for these projects has been through the ASTD program, with the balance provided by leveraged site restoration funds. The projected life-cycle cost savings from these 60 projects is more than $1 billion (DOE, 2001).

Chapter 6. However, it should be noted here that EPA has acknowledged that historically, many of its cleanup and regulatory schemes inhibited the use of innovative technologies (EPA, 1994a, 1997, 2000c), which is clearly instrumental to the success of ASM. To address this problem, EPA has issued a policy to "routinely consider innovative treatment technologies where treatment is appropriate" and to not eliminate "promising new technologies from consideration solely because of uncertainties in their performance and cost" (EPA, 2001). To promote the use of innovative technologies, EPA has even agreed to reimburse up to 50 percent of the cost of implementing an innovative remedy at select Superfund cleanup sites (EPA, 1996, 2001), although few private parties have offered to participate. In addition, EPA's policy is to promote the use of federal facilities as demonstration and testing centers for innovative environmental technologies (EPA, 1994b, 1998). In light of the importance of such centers to the adoption of ASM, this policy should be embraced wherever possible.

Socioeconomic Issues

Social and economic incentives to not invest in and utilize innovative technologies also present barriers to the evaluation and experimentation track of ASM. First, the market value of innovative remediation technology companies since 1990 has been poor. For example, stocks of most of the environmental technology companies that dropped in value in the mid-1990s (NRC, 1997) remain low, or the companies have gone out of business. Because most innovation in the private sector stems from research performed by small, innovative technology companies that are funded by private capital, investors will abandon a sector that consistently underperforms (in terms of profit). Second, the market is inherently fragmented in terms of the types of wastes, the size of the sites, the many different contaminated media involved, and the differences between federally owned sites, private sector sites, and sites cleaned up pursuant to state programs. The number of private sector companies involved in innovative remediation technology research is relatively small compared to the number of companies that have been named as potentially responsible parties across the country. This fragmentation means the inherent reward of investing in technology is smaller than if the market segments were broader. Third, the method by which future costs are calculated provides an incentive to clean up a site until it is health protective, but not to clean it up to unrestricted use (NRC, 1997). As EPA notes, there are "numerous financial incentives to delay remediation and few incentives to carry out remediation in a timely manner" (EPA, 2000c). Because of the private sector's limited investment in innovative technology development, only by increasing the level of federal research can there be any hope that new technologies capable of attaining cleanup goals will be developed.

The environmental arena has also begun, for many reasons, to accept more remedies where contamination is left in place, which could discourage evaluation and experimentation efforts. NRC (1997) concluded that "in the absence of assessing liability for cleaning up contaminated sites and posting this liability on the corporate balance sheets, there is no economic driver for improved remediation." As noted in Chapter 1, government regulatory agencies increasingly have accepted containment for at least part of the site. Without a clear legal mandate requiring cleanup of soil and groundwater to unrestricted use levels, there is less economic incentive for potentially responsible parties or private sector companies to invest in the development of new remediation technologies (NRC, 1997).

Many authors (including EPA) have reported a cultural bias against innovative approaches, not just within EPA, but also within the companies liable for the cleanup (EPA 1996, 2000c; NRC, 1997; Presidential/Congressional Commission on Risk Assessment and Risk Management, 1997). And historically, neither the public nor PRPs typically favor research (EPA, 2000c). For the public, a primary concern is that research will delay the onset of remediation—a concern that is addressed in ASM by having evaluation and experimentation occur in parallel with remedial activities. Many private sector companies and government PRPs prefer certainty. By definition, an innovative technology is less certain to achieve site cleanup goals. However, a directed study with the potential to increase overall effectiveness and reduce unit cost may be perceived differently.

Clearly, a bias against the evaluation and experimentation track is that the research may not necessarily be applicable to the site of interest. Public-private partnerships may aid in overcoming this obstacle. For example, at the Army's Fort McCoy, researchers from the University of Wisconsin Geology and Geophysics Department are helping to build a database on petroleum cleanup. They have conducted field workshops at one of Fort McCoy's remediation sites. An Army spokesman said, "Although study results may not aid Fort McCoy directly, the results are of value to the scientific community and do help build and improve the overall database on removing contaminants. The information can be used to help clean up other contaminated sites, which might include other Department of Defense sites." This partnership is succeeding because the Army provides the site, the infrastructure, and the cleanup activities to study, but it does not financially support the researchers' efforts.

MAJOR CONCLUSIONS AND RECOMMENDATIONS

Much of the short-term increased costs associated with implementing ASM in anticipated to be associated with evaluation and experimentation. However, if ASM is targeted to those high-risk, complex sites where large costs are at stake (as suggested in Chapter 2), the costs associated with ASM are likely to be balanced or exceeded by the savings that result from switching to a more efficient and effective technology or by overall life-cycle savings. An example is provided by the National Zinc NPL Site in Bartlesville, Oklahoma. After setting initial cleanup goals for heavy metals, several site-specific studies of lead, arsenic, and cadmium bioavailability were conducted. These included rat feeding studies using local contaminated soil as well as mineralogical and chemical extraction methods (NRC, 2002). After review by the lead state agency, a community advisory group, and an independent expert in the field, results from the study led to revised cleanup goals based on the measured limited bioavailability of the metals to humans. These revised values greatly reduced the aerial extent of soils requiring remediation and reduced the remediation costs by approximately $40 million, with the bioavailability studies themselves costing less than one hundredth of this cost savings. Although in this case the action involved revising a cleanup goal rather than discontinuing and replacing an ineffective remedy, it nonetheless illustrates the benefit of investing in learning as part of the cleanup process.

It is important to distinguish between ASM's evaluation and experimentation track and treatability studies under the CERCLA process. Treatability studies are generally conducted during the RI/FS or the RD/RA phases, and they provide a starting point for ensuring that a certain treatment approach or specific remedy design will be effective at the site of interest (EPA, 1992). Indeed, they can be critical to evaluating a potential remedy prior to its full-scale implementation. Although treatability studies may involve the type of experimental studies discussed as part of evaluation and experimentation, they generally occur earlier in the CERCLA process (before or during MDP1) and they do not necessarily involve experimentation on less certain technologies that could be turned to in the event of failure of the initial remedy (although they could certainly be designed to do so). Thus, as narrowly defined above, treatability studies are an important component of ASM, but they are not a substitute for evaluation and experimentation, which facilitates more informed decision making during MDP3. Because ASM involves feedback loops, treatability studies may occur multiple times during the lifetime of a hazardous waste site as different technologies are proposed and implemented.

Other than suggesting that evaluation and experimentation will be most cost-effective at complex, high risk sites, it is inappropriate for this report to make specific recommendations on cost criteria for deciding whether or not to conduct evaluation and experimentation, although the Navy and other federal agencies that adopt ASM may decide to do so. For example, agencies may prefer to allot some percentage of annual costs (capital, operation and maintenance, or combined) to enabling evaluation and experimentation and building the data infrastructure necessary to support innovative research. Or such decisions might be made on a site-specific basis to take into account the certainty of initial remedy effectiveness. Other resource allocation issues will need to be addressed in order to overcome the aforementioned barriers to research. These include the creation of incentives for site managers to conduct evaluation and experimentation and of flexibility so that site managers can respond to what may be surprising results from evaluation and experimentation efforts. These issues and others should appropriately be examined by pilot testing ASM at a few select sites, as recommended in Chapter 2.

Evaluation and experimentation are integral to adaptive site management and should occur concurrently with remedy implementation. Improved understanding of a site through evaluation and experimentation can reduce the amount of uncertainty associated with the risk estimate at a site and suggest ways to enhance the performance of the existing remedy. Evaluation and experimentation of new, innovative technologies can also help guide the selection of an alternative in case the remedy is ineffective in meeting cleanup goals. The need for making adjustments in remedial technology over time should be considered the norm, and designs should be conceptualized and implemented accordingly. Employing evaluation and experimentation is most important for remedies likely to reach an asymptote prior to meeting the remedial goal, for sites with intractable contamination such as DNAPLs and metals, and for sites where containment or institutional controls are used.

Stakeholders should help define the research objectives for developing innovative technologies that can respond to difficult site-specific cleanup challenges. Public involvement during evaluation and experimentation efforts can help to expand the number of acceptable remediation technologies that are considered, build trust, and reduce uncertainty in the cleanup process. An engaged and informed public is better prepared to participate in the review of technology options and to understand the technical limitations.

DoD should better promote testing of innovative or new experimental technologies at selected sites both for site-specific application and if the results are likely to improve cleanup activities at other sites. Long-term cost and performance data are unavailable for most innovative technologies, making it impossible to fully evaluate their success or efficacy. Consequently, quantitative comparison of these technologies to more traditional remedies also is difficult, especially in terms of reduction in risk or exposure versus cost or time.

DoD should expand its programs that focus on developing and testing innovative remedial technologies and monitoring techniques. It appears certain that a number of DoD and other sites will require costly, substantive management for decades or longer. Therefore, in the absence of enabling legislative or regulatory changes, the lack of such research will result in DoD and others not having the new tools that can improve remedial programs and reduce long-term fiscal liabilities. Responsible federal agencies should collaborate closely with researchers in the public and private sectors to ensure that RPMs are trained and knowledgeable on new and innovative technologies that might be used to replace existing ineffective remedies.

Congress should make sure there are funds available to support the evaluation and experimentation track of adaptive site management. Although significant research efforts have been underway, unless the federal government provides new resources, only slow progress will be made toward finding cost-effective methods of reducing contaminant levels and meeting cleanup goals. Federal support is needed to fill the gap left as a result of lacking market incentives for the development of innovative hazardous waste cleanup technologies.

Resource, timing, regulatory, and socioeconomic obstacles need to be overcome in order to fully adopt evaluation and experimenta-

tion as a component of ASM. Combining research and development activities in conjunction with cleanup has value, but additional resources beyond those needed to implement the chosen remedy are generally not available with current cleanup programs. Site managers often perceive the results from research as yielding answers over time scales that are too long to prove useful in optimizing existing remedies or in making informed decisions about when to replace a remedy. A final obstacle to evaluation and experimentation is that social and economic incentives for investing in and utilizing innovative technologies are limited. The increasing use of containment and institutional controls has discouraged additional investment in the development of new remediation technologies.

The Navy and, more generally, DoD should make site-specific operations data for a select number of complex sites more easily accessible to the research community. Making such data available would facilitate the development of new monitoring techniques, remediation technologies, and predictive modeling for hazardous waste sites. In addition, if DoD and EPA managed site-specific data in a uniform manner and made these data easily accessible to researchers, other RPMs, and the public, it would be easier to identify what technical barriers are preventing attainment of cleanup goals at sites.

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